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By J. F. Hamlet and R. G. Adams
Astrionics Laboratory

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TECHNICAL MEMORANDUM X- 64643

SLUSH HYDROGEN LIQUID LEVEL SYSTEM

SUMMARY

This report describes a discrete capacitance liquid level system developed specifically for slush hydrogen, but applicable to lox, LN_2 , LH_2 , and RP1 without modification. The signal processing portion of the system is compatible with conventional liquid level sensors. Compatibility with slush hydrogen was achieved by designing the sensor with adequate spacing, while retaining the electrical characteristics of conventional sensors. Tests indicate excellent stability of the system over a temperature range of -20°C to 70°C for the circuit and to cryogenic temperatures for the sensor. The sensor was tested up to 40 g's rms random vibration with no damage to the sensor. Operation with 305 m of cable between the sensor and signal processor was demonstrated. The system can be modified for water calibration. From the results outlined in this report, it is concluded that this design is more than adequate for most flight and ground applications.

It is recommended that this basic design, with packaging modified as required, be adopted for all new applications at the Marshall Space Flight Center (MSFC) and the Mississippi Test Facility.

INTRODUCTION

The measurement of the quantity of liquid hydrogen or computation of liquid hydrogen flow rates from a tank is typically made via capacitance discrete liquid level measurements. Conventional liquid level sensors will not operate in slush hydrogen because of becoming clogged with the solid particles.

A capacitance discrete liquid level system was designed for the slush hydrogen facility at MSFC. Capability is provided for operation with other media. Operation with slush hydrogen was achieved by large electrode spacing. The signal processor is rack-mounted, printed circuit plug-in construction, with capability for handling up to 20 liquid level probes. This report presents the detailed system explanation, test results, and operating instructions for the system.

SLUSH HYDROGEN LIQUID LEVEL SYSTEM.

The slush hydrogen liquid level system consists of the following items:

1. Slush Hydrogen Liquid Level System Electronics Model 101 (Figs. 1 and 2). The components comprising the electronics unit are as follows:

- a. Power supply (Figs. 3 and 4).
- b. Oscillator and amplifier (Figs. 5 and 6).
- c. Amplifier (Figs. 7 and 8).
- d. Chassis (Fig. 9).

2. Slush Hydrogen Liquid Level Probe (Fig. 10).

The electronics is designed for maximum flexibility so that it can be used without any modification with liquid level probes in slush hydrogen, LH_2 , lox, LN_2 , and RP1. Detailed information is given later.

Significant features of the system include capability of operating with long cable lengths using low excitation output impedance and low amplifier input impedance. The system has exceptional stability and a high degree of flexibility.

The cabling between probes and electronics should be coaxial, not exceeding 100 pF/m capacitance. The probes should be connected to a common excitation cable as close to the probes as practical to avoid cable loading on the excitation voltage. The maximum allowable cable length depends on parameters such as quadrature currents and operating media. However, the system should be usable with up to at least 914 m of cable. As the cable becomes longer, the need for the quadrature adjustment increases.

The output of the electronics unit is located on the rear panel and consists of a Bendix PT07-16-26S connector with pin designations as follows:

<u>Pin</u>	<u>Channel</u>	<u>Pin</u>	<u>Channel</u>
A	1	H	8
B	2	J	9
C	3	K	10
D	4	L	11
E	5	M	12
F	6	N	13
G	7	P	14

<u>Pin</u>	<u>Channel</u>	<u>Pin</u>	<u>Channel</u>
R	15	V	19
S	16	W	20
T	17	<u>b</u>	0 Vdc
U	18	<u>c</u>	0 Vdc

CIRCUIT DESCRIPTION

General

The circuit block diagram is shown in Figure 11. The circuit is housed in a rack-mounted panel and provisions are made for the rack to accept one power supply board, one oscillator board, and up to 20 amplifier boards.

The liquid level probes are connected in a transformer ratio arm bridge and the unbalanced bridge signal is amplified and detected to provide the output. The basic bridge consists of T51, C16, and the liquid level probe, with the bridge signal being developed in T2. The T51 secondary windings on each side of the bridge ground form two arms of the bridge while C16 and the probe form the other two arms. There is one bridge for each probe, with T51 being common for all probes. The bridge is designed for a nominal probe empty capacitance of 5 pF. Other values can be accommodated by changing C16, if R30 will not allow sufficient adjustment. If probes of different capacitance are used, the variable capacitance values specified in the adjustment procedures are not adequate.

Power Supply Board

The power supply is a double full-wave rectifier supplying approximately ± 26 Vdc with series regulation to provide ± 12 Vdc. The series regulator transistors and the power transformer are mounted on the chassis. The regulator output voltage is set at ± 12 Vdc by selection of R1, R2, R3, and R4. An unfiltered voltage of approximately 25 V peak is provided to drive the output indicator lamps and test relay.

Oscillator and Amplifier Board

The oscillator, Q51 and associated circuitry, supplies the probe excitation signal at approximately 10 kHz. Q52 and Q53 provide buffering between the oscillator and bridge transformer T51. The output voltage between the LH₂

excitation terminal to bridge ground is approximately 10.5 volts peak-to-peak (V_{pp}). The excitation voltages for LN_2 , lox, and RP1 are supplied at lower voltages corresponding to the dielectric constant. This allows simultaneous operation of probes in LH_2 , LN_2 , lox, and RP1 from one rack. Other liquids can be accommodated by special selection of C16 on the amplifier board. Normally the amplifier circuit, Q1 through Q8 and associated circuitry, is not installed on this board.

Relay RL1 provides a rough test for proper circuit operation. This test can be used only for probes that are dry. If, upon energizing RL1, an output indicating a wet probe appears on any channel, it indicates that the probe is connected and the circuit is operating.

Amplifier Board

The amplifier board contains the signal conditioning circuitry for one liquid level probe. Q1, Q2, and Q3 amplify the bridge ac output signal. Q4 and Q5 form a phase detector with differential output voltage proportional to bridge unbalance. This dc differential voltage is amplified by Q8, connected in an open loop mode, to provide the on-off discrete output. The output should switch from full-on to full-off within a capacitance change (ΔC) of 0.01 pF. A positive output indicates the probe is covered by liquid. The magnitude of the output voltage can be selected, up to approximately 10 V, by the voltage divider formed by R20 and R21. A visual output is provided by the lamps, L1 through L20, driven by Q6. The lamps are illuminated when the probe is covered. Q7 provides isolation for the reference phase voltage. R24, R25, R26, and C12 allow the phase of the reference voltage to be adjusted to account for phase shifts in the bridge output voltage. For some applications, R24 may be a fixed resistor. The quadrature adjustment, R29, may be deleted for some applications where quadrature currents are not a problem.

Circuit Options

A minor circuit modification allows the system to be used for continuous liquid level measurements if desired. This is accomplished by the addition of R32, which reduces the gain of Q8, and the selection of C16 to accommodate the continuous probe empty capacitance. C7 is added to reduce ripple on the output. The existing circuitry can accommodate a full scale ΔC of up to 8 pF when the LH_2 excitation is used and up to 12 pF when the RP1 excitation is used. Larger full scale ΔC can be accommodated by increasing R10 on the amplified board to

avoid saturating the ac amplifier or by reducing the excitation voltage by changing R51 on the oscillator board. The circuit is temperature sensitive when used in the continuous liquid level mode and should not be used when ambient temperature varies if accurate data are required.

Provisions are made whereby in-phase bridge null can be adjusted simultaneously for all probes from the oscillator board by way of R56, if desired. This adjustment is not as exact as the individual adjustment for each channel. If R56 is used, it should be 5 to 10 Ω and will eliminate the need for R30 on the amplifier boards. The following steps should be taken to set up the circuitry for using R56.

1. Install R56 (5 to 10 Ω).
2. Remove jumper J1 on the oscillator board.
3. Connect pin 1 to pin 10 on oscillator board.
4. Remove R30 on all amplifier boards.
5. Connect pin 4 on amplifier boards to C16.

The adjustment procedure for R56 will be the same as for R30 except it is adjusted for only one amplifier. If switch points of other amplifiers are not within tolerance, C16 will have to be selected to closer tolerance for these boards. Absolute maximum switch point tolerances, in picofarads, are listed below.

	<u>LH₂</u>	<u>LN₂</u>	<u>Lox</u>	<u>RP1</u>
Nominal	5.575	6.075	6.200	7.700
Minimum	5.300	5.400	5.500	6.100
Maximum	5.800	6.600	6.800	9.300

Note also that one amplifier channel can be incorporated on the oscillator board for applications requiring only one amplifier and there is no need for a complete rack. However, space for the lamp driver output transistor, Q6, is not provided on this board.

Water Operation

Minor circuit modification will allow the system to operate in water as required; for example, when in-place calibration is required. The required modifications are as follows:

1. Excitation of probe is from the gray/white tap of T51 to provide lower voltage and impedance.
2. R29 is changed to 100 Ω and R31 is changed to 330 Ω to allow the bridge to be nulled with the probe half full of water.
3. R33 is changed to 0 Ω to reduce the gain of the ac amplifier to avoid saturation caused by the high level signal in water.
4. Adjustment of R24 is required to make the phase detector sensitive to the quadrature signal caused by water in the sensor.

CAPACITANCE PROBE

The capacitance probes (Fig. 10) consist of four concentric rings with alternate rings connected together. One pair of rings is connected to the excitation voltage supplied by the electronics unit and the other two rings provide the signal output. The signal and excitation leads are coaxial cables with their shields connected to the frame of the sensor, which provides a guard between the electrodes.

The spacing of the rings is 1 cm (0.4 in.), which is sufficient for slush hydrogen to pass through them without clogging. The support structure for the rings is tapered; i. e., it comes to a knife edge, so that slush will not build up on top. The wide spacing should offer significant advantage for application when extremely fast response is required, because surface tension would not cause fluid to be collected between the electrodes.

TEST RESULTS

The following tests were performed on the system to determine if the design is adequate for its intended use.

Vibration (Sensor Only)

1. Vibration Criteria. Sine vibration at a 5-g peak, 20 to 2000 Hz. Random vibration at $0.8 \text{ g}^2/\text{Hz}$, 20 to 2000 Hz.

2. Results. No capacitance change or resonance during sine vibration. Capacitance change of 0.15 pF during random vibration. This is not a permanent shift. The allowable tolerance is $\pm 0.3 \text{ pF}$.

Temperature

1. Amplifier and Oscillator. The amplifier and oscillator were tested at -20°C and 70°C with maximum deviation in switch point of 0.02 pF. Allowable tolerances are $\pm 0.3 \text{ pF}$.

2. Sensor. The sensor was thermally shocked and tested functionally in LN_2 . No problems resulted from shock, and functional tests indicated that all of the probe capacitance was active, as would be expected with the grounded guard construction.

Operation with Long Cables Between Sensor and Circuitry

The system was tested with 305 m of cable between the sensor and circuitry. Operation was excellent with only very minor adjustments required when changing from 0 to 305 m of cable.

Slush Hydrogen Operation

The sensor was tested in slush hydrogen at the National Bureau of Standards, Boulder, Colorado, to verify that slush would not collect in the sensor. There was no slush buildup in the sensor.

Operating Media Test

The capability of the circuitry to operate the sensor in different media was verified by laboratory tests in which sensors were simulated.

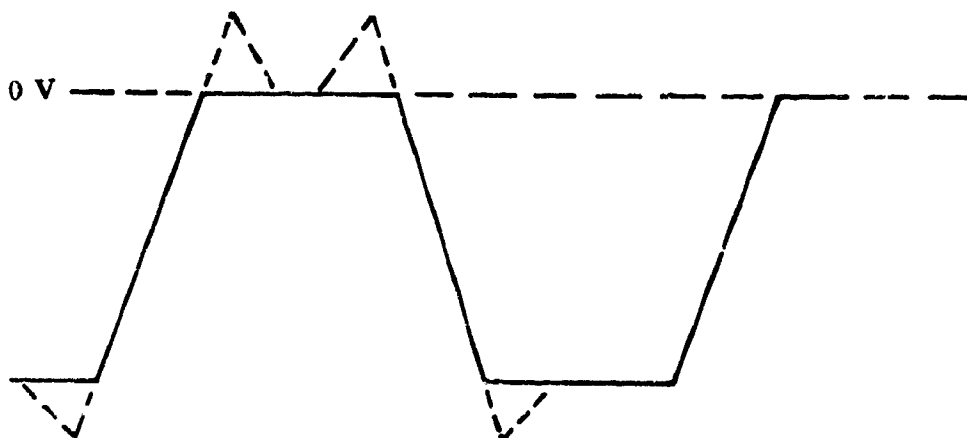
Water Operation Tests

The circuitry was modified for water operation and was verified. Based on previous tests, it is concluded that the performance of the system is more than adequate for most applications.

ADJUSTMENT PROCEDURE

Discrete Probe Operation

1. Connect all probes and allow 5 min for circuit warmup.
2. Connect a variable capacitor between the LH_2 excitation and the channel to be adjusted and set capacitor to 0.575 pF. Connect one channel of a dual channel oscilloscope to test point (TP)1. Adjust R29 and R30 for null at TP1. Null should be less than 200 mVpp.
3. Increase the variable capacitor to approximately 2 pF. Connect other channel of the oscilloscope to TP2. Adjust R24 until the signal at TP2 is in phase with the signal at TP1. (R24 will be at the most clockwise position and at maximum resistance for short cables.) Note that if a dual channel oscilloscope is not available, R24 can be adjusted as follows: Increase the variable capacitor to approximately 2 pF, connect an oscilloscope to TP3, and adjust R24 until the signal at TP3 appears as shown in the following sketch. There should be no peaks as shown by the dotted lines.



4. Decrease the variable capacitor to 0.575 pF. Adjust R30 until the output switches as indicated by the lamps or the output voltage. (Turn R30 clockwise to turn lamp on.)

5. Remove the variable capacitor and repeat steps 2 through 5 for all channels.

Continuous Liquid Level Probe Operation

1. Select C16.

C16 = 18 empty capacitance if LH₂ excitation is used.

C16 = 13 times the empty capacitance if RPI excitation is used.

2. Select voltage divider resistor R20 for desired full scale output voltage. If negative output is desired, diode CR1 must be shorted.

3. Connect probe and allow 15 min for circuit warmup.

4. Connect oscilloscope to TP1 and adjust R29 and R30 for null at TP1. Null should be less than 200 mVpp.

5. Connect a capacitor, equal to the expected full scale ΔC of the probe, across probe. Adjust R24 until signal at TP2 is in phase with signal at TP1. Select the value for R32 to provide desired sensitivity,

$$\frac{\text{output voltage}}{\Delta C \text{ input}}$$

6. Calibrate the system and disconnect variable capacitance. System is ready for operation.

TROUBLESHOOTING CHART

Oscillator Board

Note: All excitation jacks are disconnected.

<u>Component</u>		<u>Voltage Reading</u>	
		<u>ac</u>	<u>dc</u>
Q51	e	0.6 Vpp	-
	b	0.3 Vpp	-
	c	22 Vpp	-
Q52	e	21 Vpp	-
Q53	e	21 Vpp	-
LH ₂ Excitation		11 Vpp	-

Amplifier Board

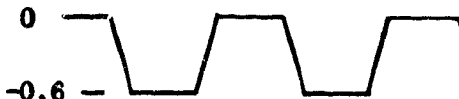
Note: Voltages are measured under the following conditions:


1. R32 = ∞
2. Bridge is null for dc measurements.
3. Bridge is unbalanced by 2 pF for ac measurement.

<u>Component</u>		<u>Voltage Reading</u>	
		<u>ac</u>	<u>dc</u>
Q1	e	0	2.4 V
	b	0	3.1 V
	c	0.008 Vpp	4.2 V
Q2	e	0.004 Vpp	3.6 V
	b	0.008 Vpp	4.3 V
	c	0.035 Vpp	7.2 V

ComponentVoltage Reading

Q3	e	0.008 Vpp	0.030 V
	b	0.015 Vpp	0.650 V
	c	1.800 Vpp	3.900 V

Q4	e	
----	---	--

Q5	e	
----	---	---

Q7	e	7.0 Vpp
----	---	---------

T3, Pin 6	2.5 Vpp
T3, Pin 4	2.5 Vpp

Power Supply Board

ComponentVoltage Measurementdc

Q1	e	-6.0 V
	b	-6.4 V
	c	-14.0 V

Q2	e	+8.7 V
	b	+10.0 V
	c	+12.6 V

Q4	e	+12.4 V
	b	+12.6 V
	c	+25.0 V

Q5	e	+22.0 V
	b	+21.0 V
	c	+12.6 V

<u>Component</u>		<u>Voltage Measurement</u>
		<u>dc</u>
Q6	e	-25 V
	b	-25 V
	c	-14 V
Q7	e	-12.8 V
	b	-14.0 V
	c	-26.5 V

CONCLUSIONS AND RECOMMENDATIONS

The slush hydrogen liquid level system design is more than adequate for most flight and ground applications. The design is simple, easy to duplicate, and presents no hazards because of materials or power requirements.

It is recommended that this system be adapted for discrete liquid level measurements in all ground systems of MSFC and for selected flight applications where fast response, operation with extremely long cables, or operation in slush is required.

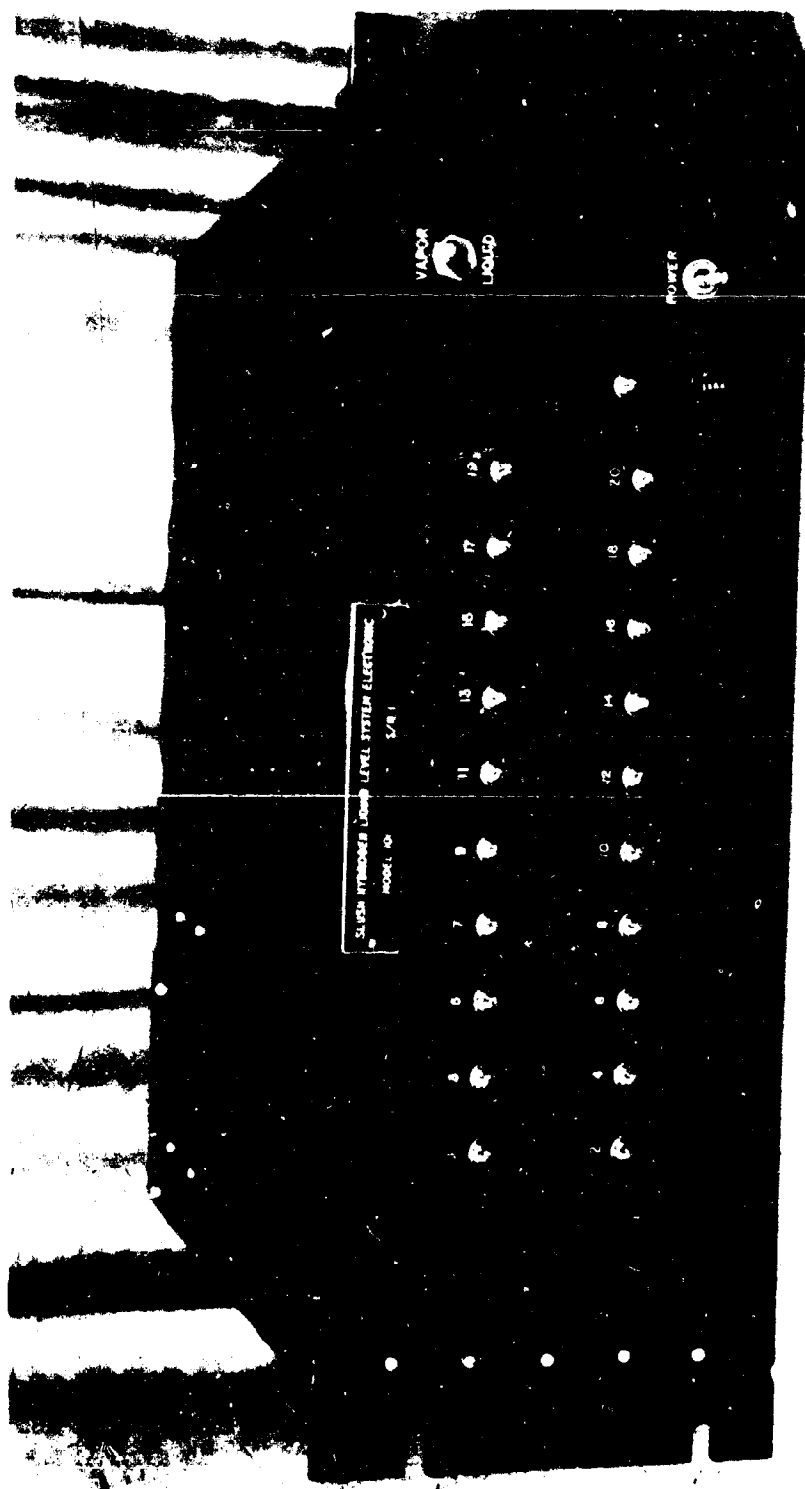


Figure 1. Slush Hydrogen Liquid Level System Electronics Model 101, front view.

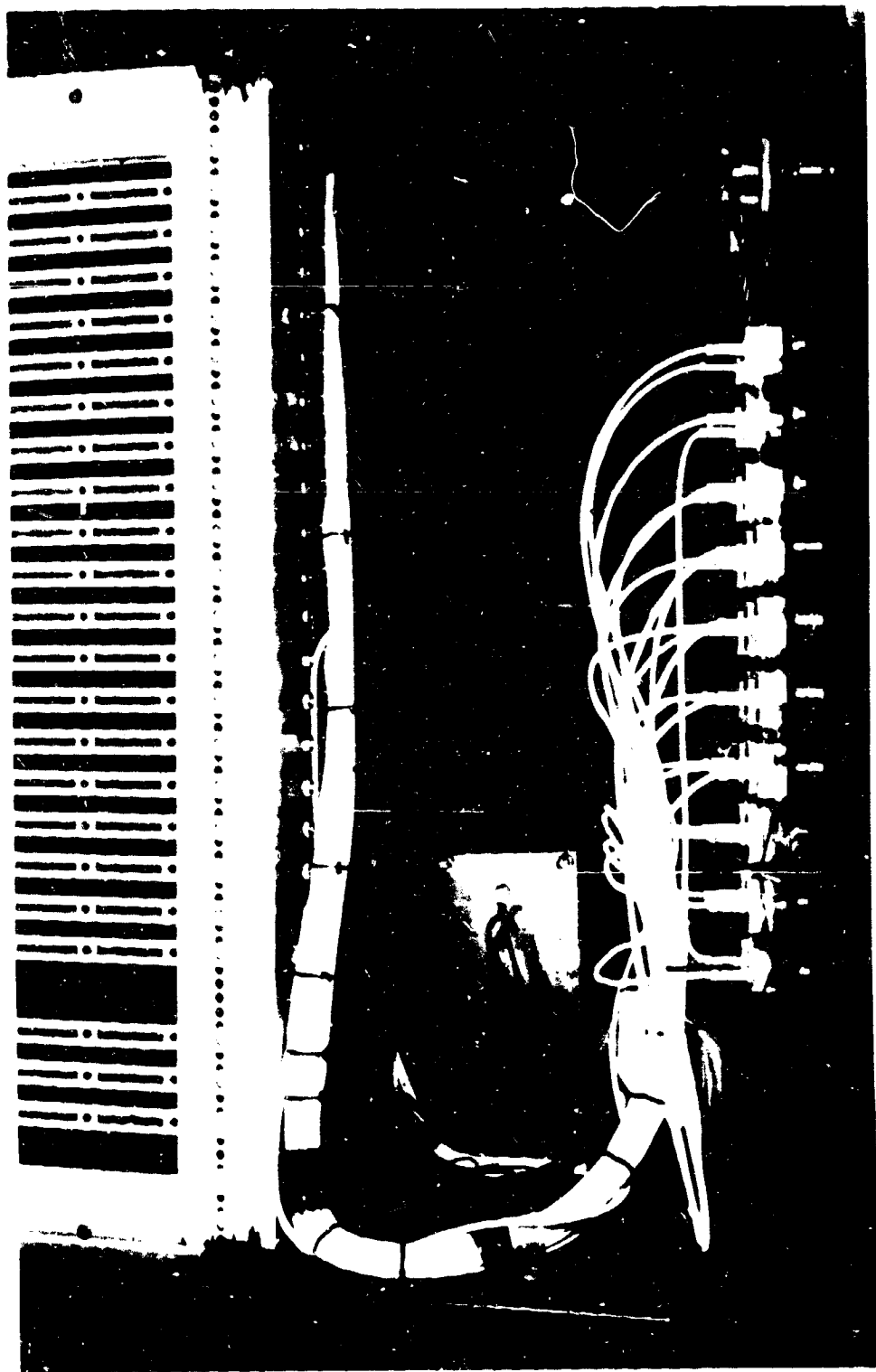


Figure 2. Slush Hydrogen Liquid Level System Electronics Model 101, top view (cover removed).

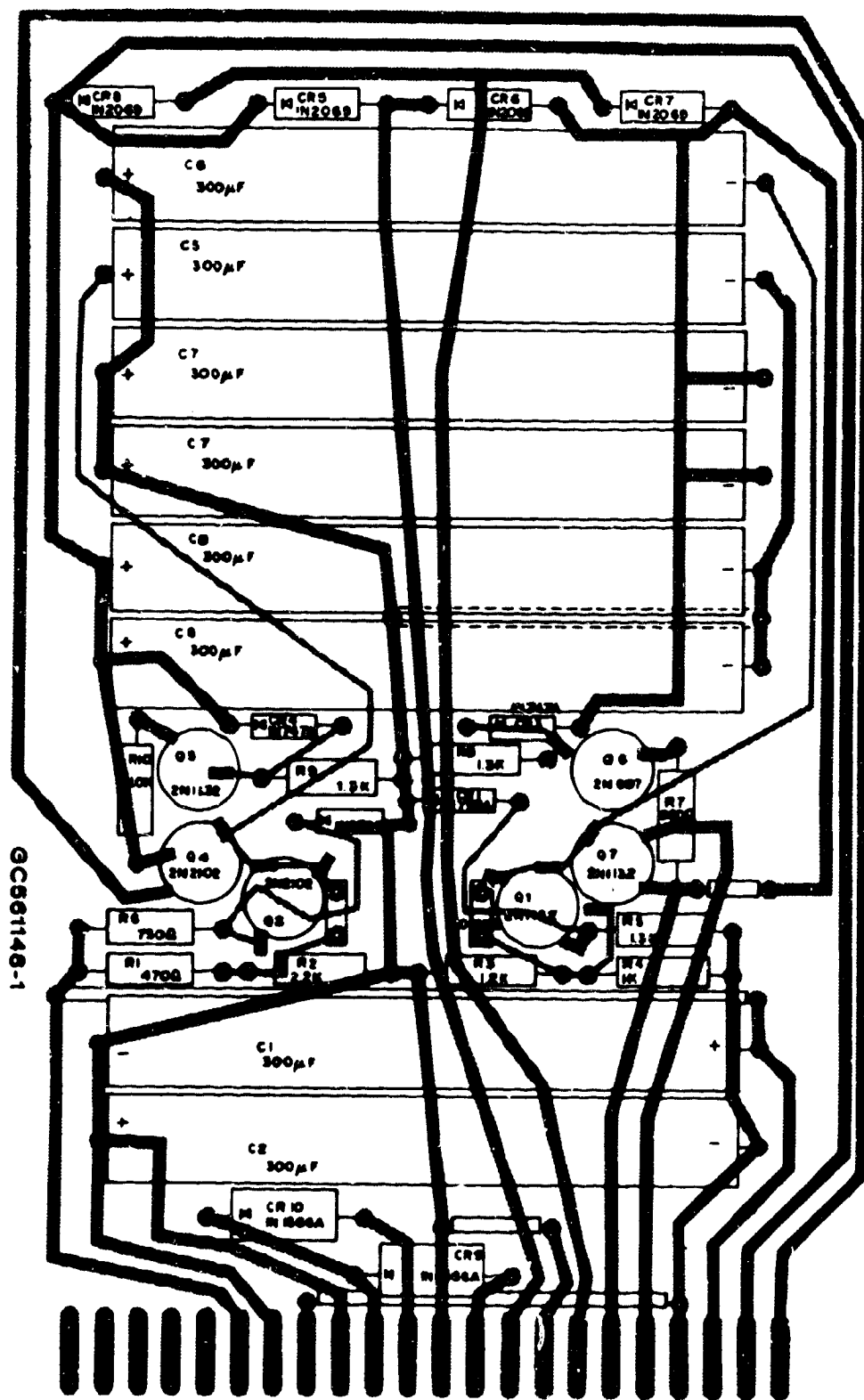
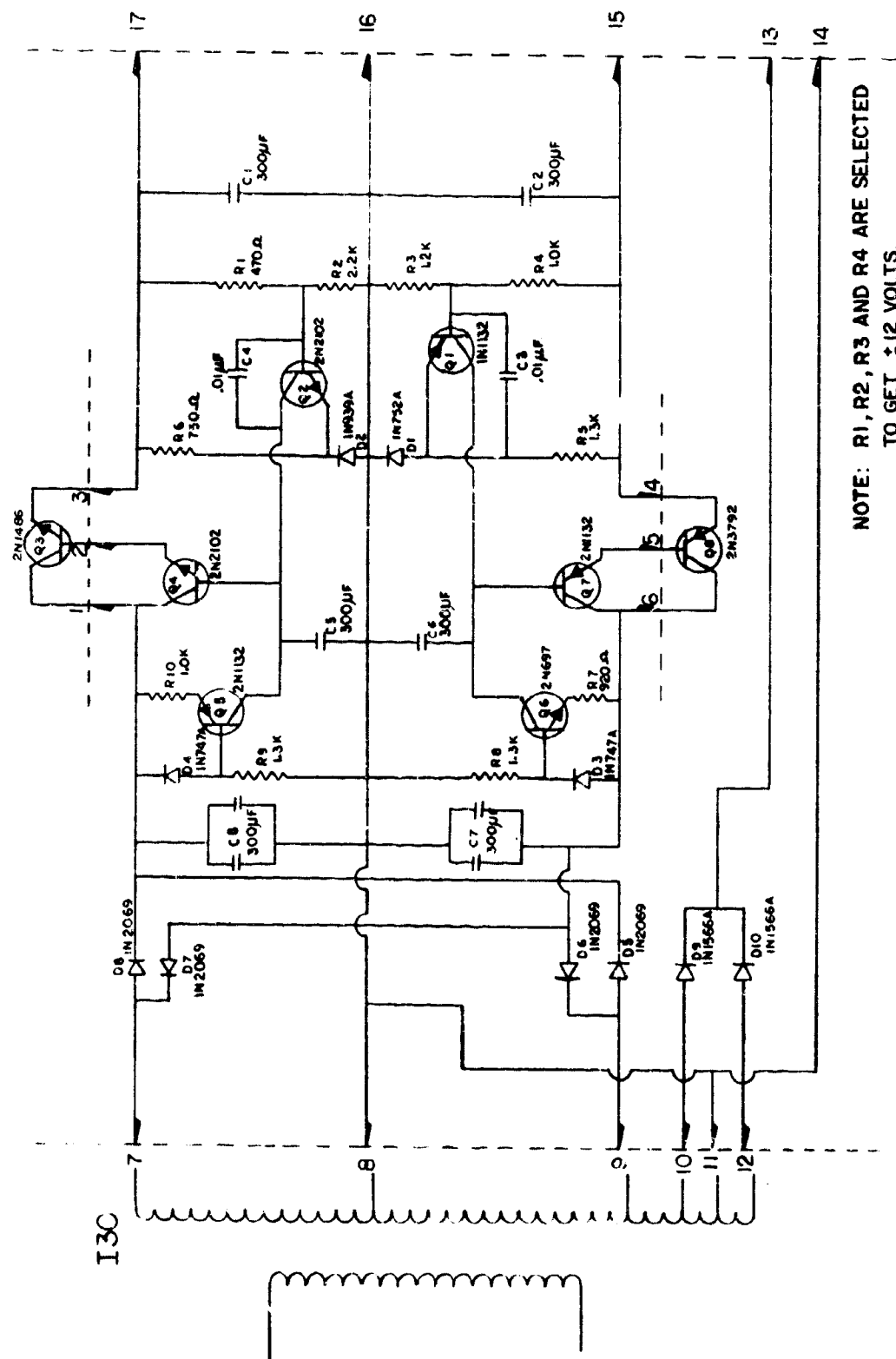


Figure 3. Power supply PC board.



NOTE: R1, R2, R3 AND R4 ARE SELECTED
TO GET ± 12 VOLTS.

Figure 4. Power supply schematic.

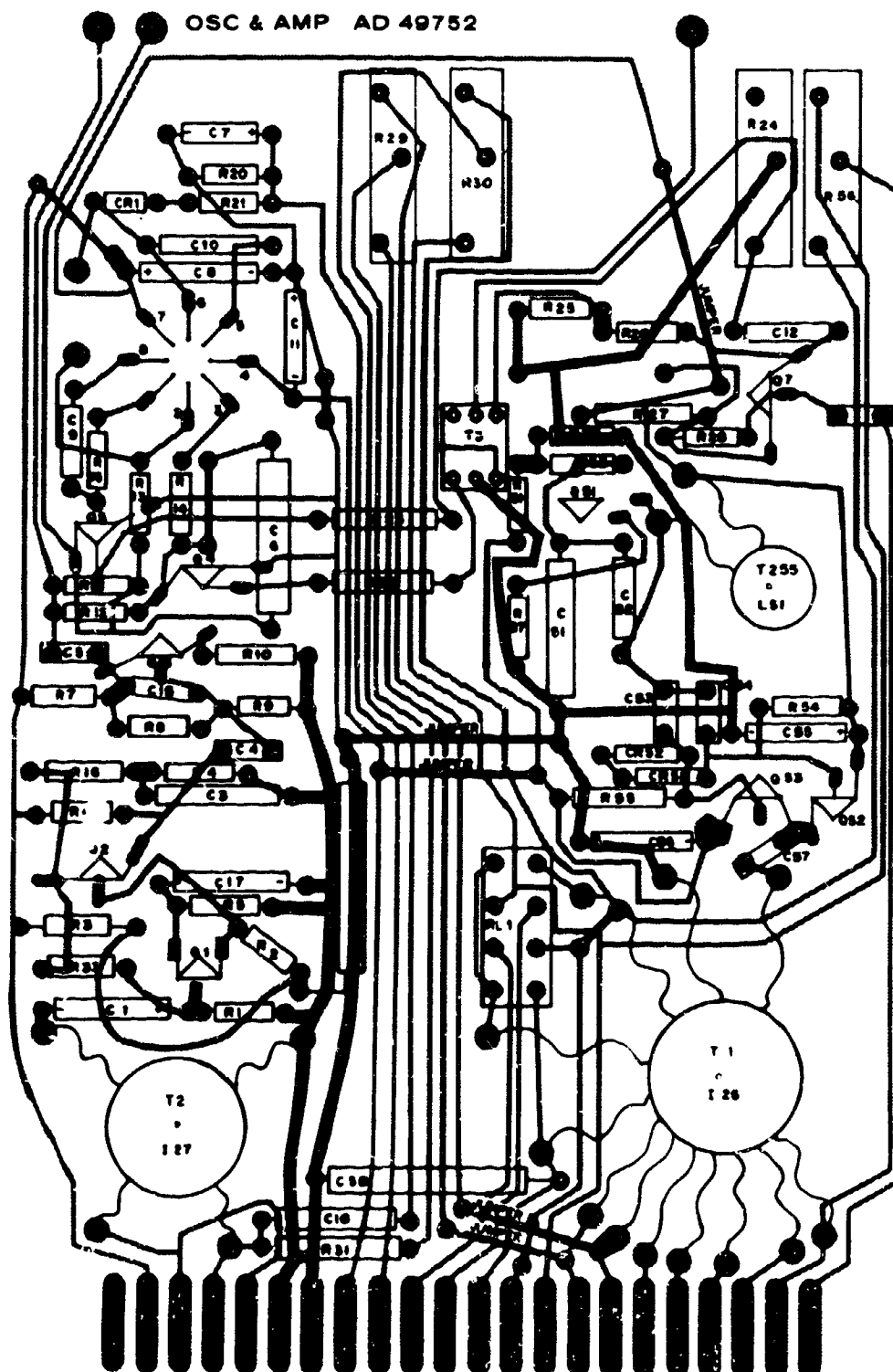


Figure 5. Oscillator and amplifier PC board.

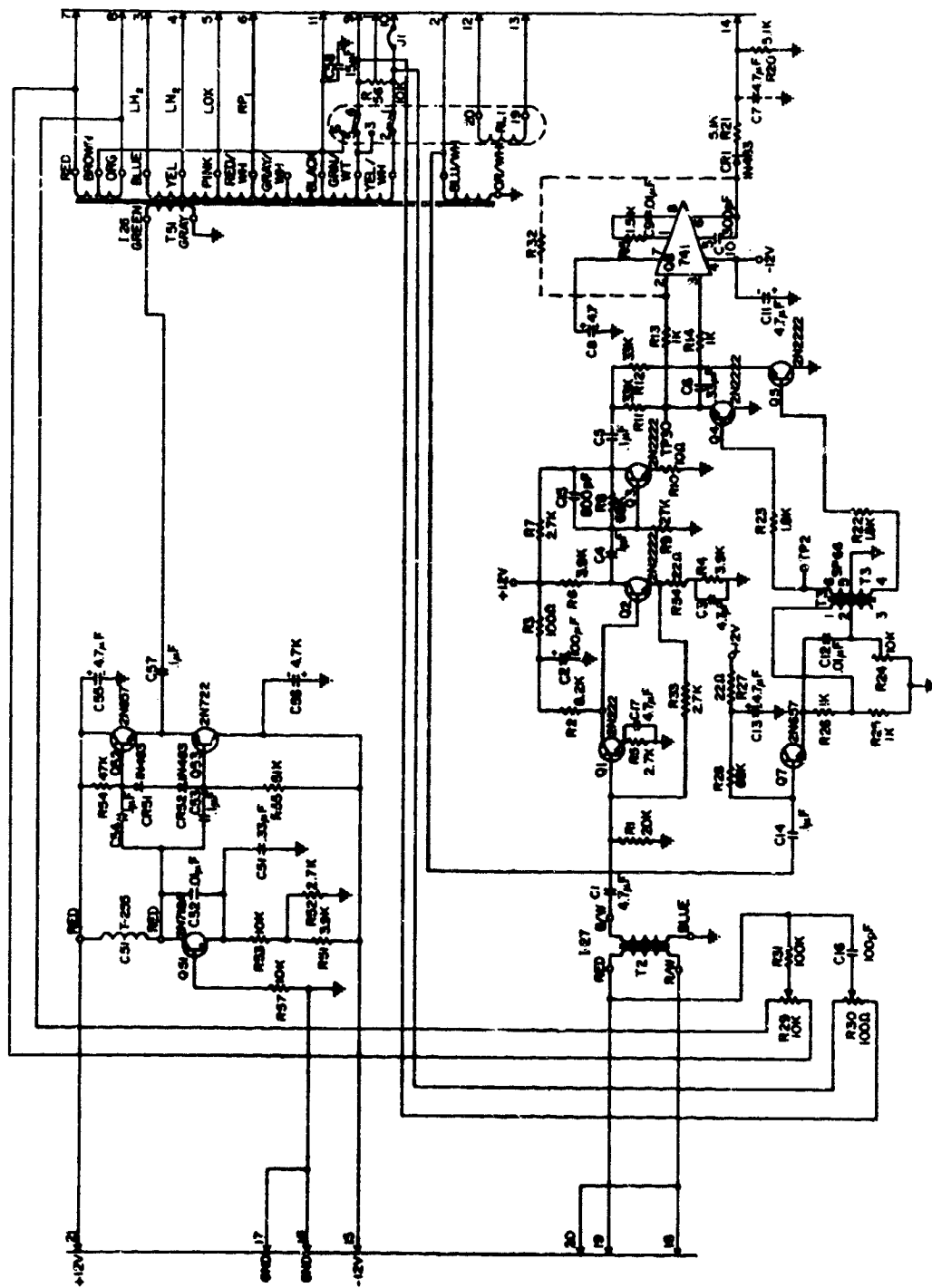


Figure 6. Oscillator and amplifier schematic.

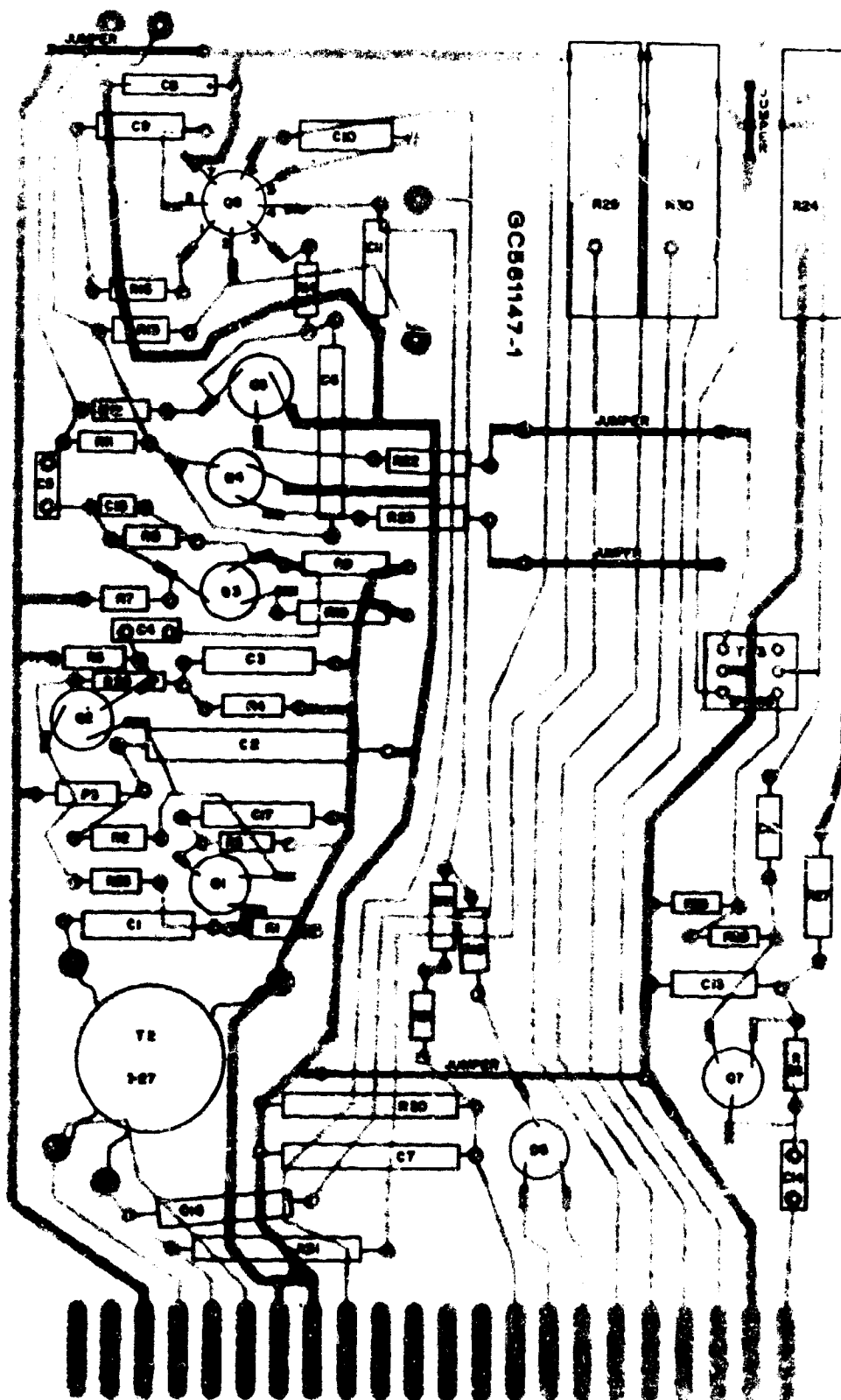


Figure 7. Amplifier PC board.

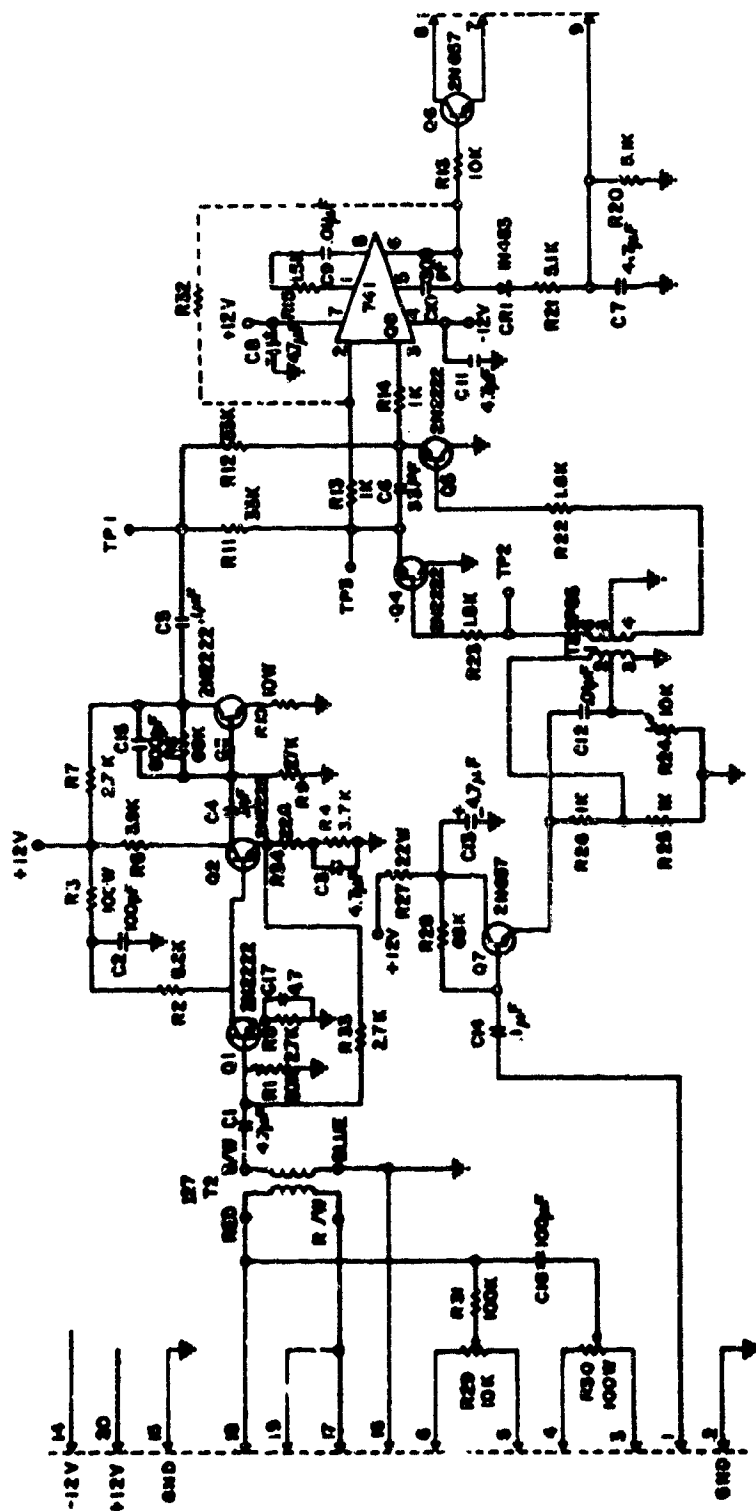


Figure 8. Amplifier schematic.

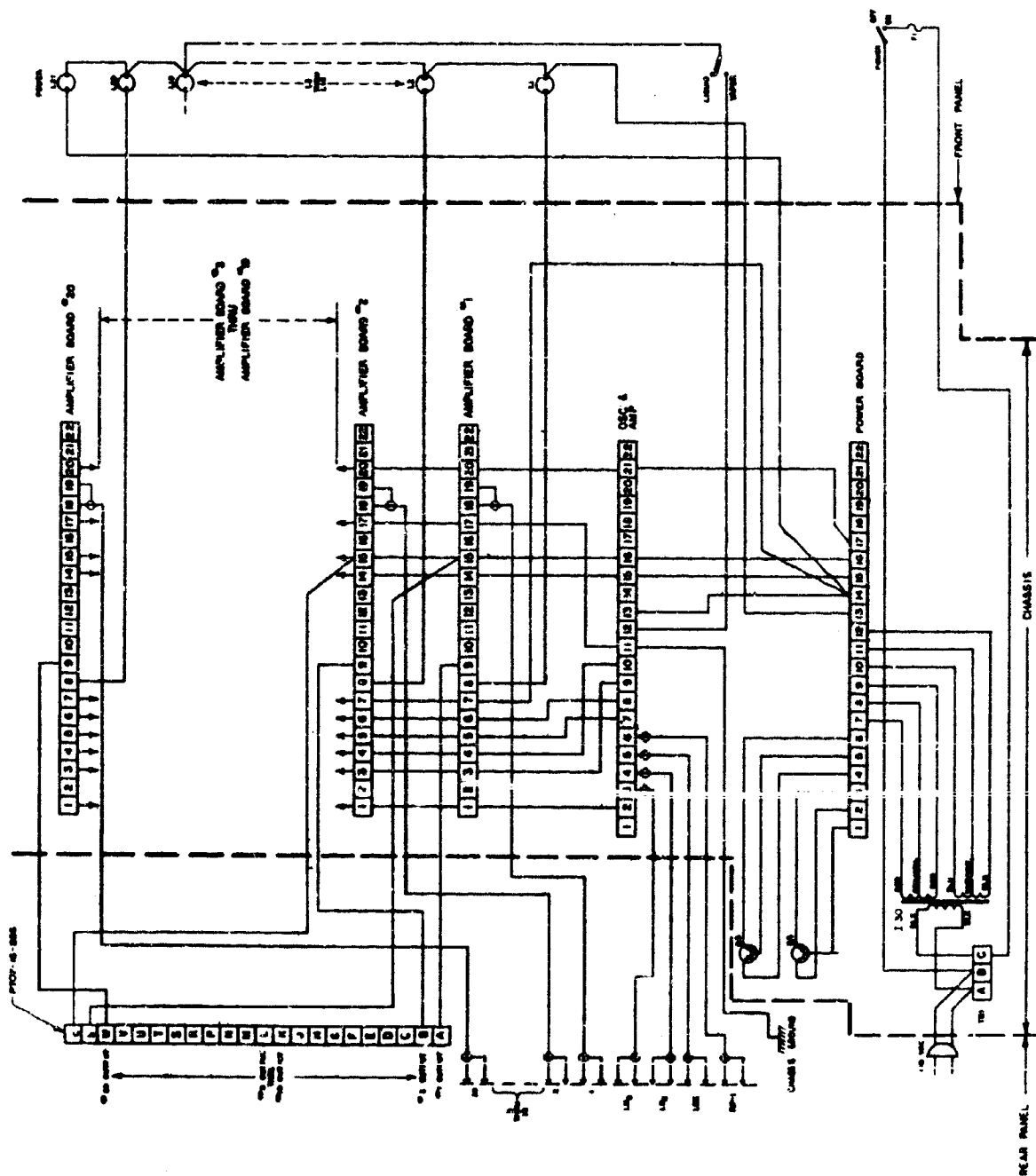


Figure 9. Chassis wiring diagram.

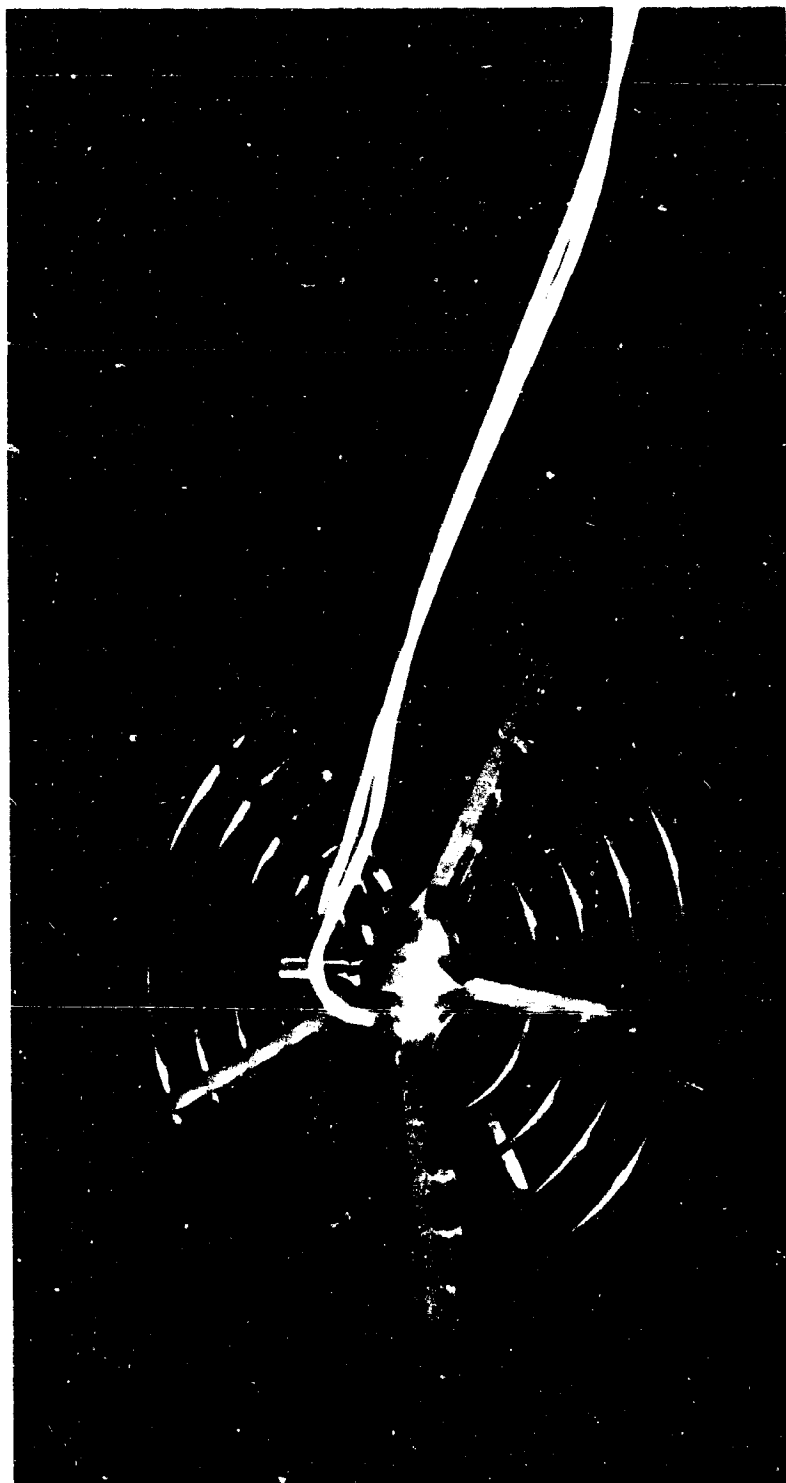


Figure 10. Slush hydrogen liquid level probe (capacitance probe).

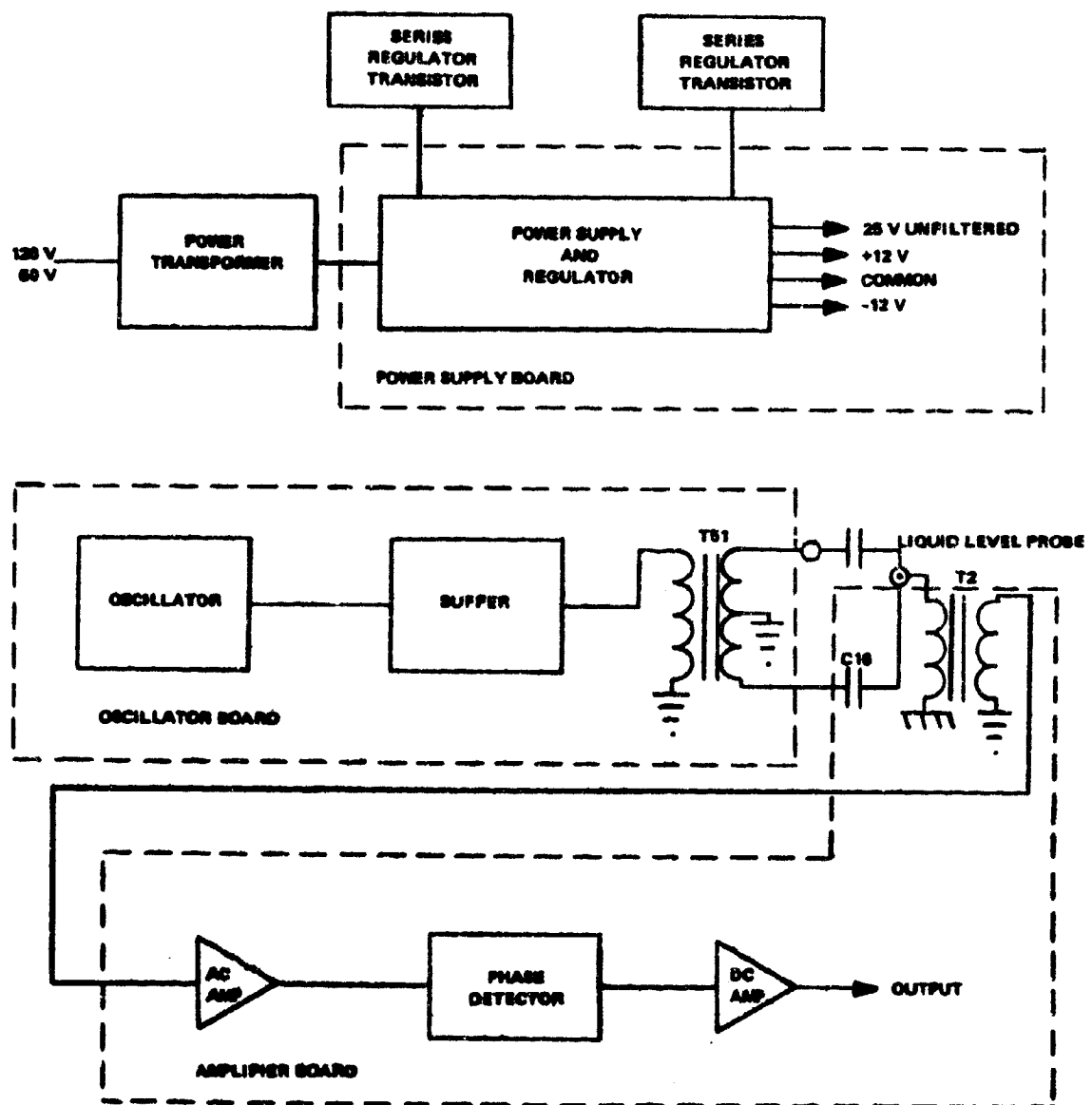


Figure 11. Circuit block diagram.

APPROVAL

SLUSH HYDROGEN LIQUID LEVEL SYSTEM

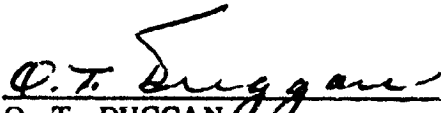
By J. F. Hamlet and R. G. Adams

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.



W. T. ESCUE
Chief, Measuring and Instrumentation Branch



O. T. DUGGAN
Chief, Instrumentation and Communication Division



F. B. MOORE
Director, Astrionics Laboratory